Use of the Semmes–Weinstein 5.07/10 Gram Monofilament: the Long and the Short of it

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The Semmes–Weinstein monofilament has been developed for the detection of patients at risk of neuropathic ulceration. In this study we evaluated how the physical characteristics of the monofilaments can impact on their performance. Commercially purchased monofilaments from the Hansen's Disease Center (HDC) and a batch produced 'in-house' (RPAH) were calibrated using a Mettler Balance. To assess the effects of varying lengths on buckling force, the monofilaments were tested repeatedly while the length of the filament was reduced stepwise from 4.1 to 3.1 cm. The correct length of the monofilament to generate a buckling force of 10 g was also determined theoretically by applying the Euler's Buckling Equation. Results showed neither batch of monofilaments buckled at a strength of 10 g (HDC 6.8 g, CI 5.7–7.9, and RPAH 7.2 g, CI 7.1–7.3). In addition HDC showed a wide interfilament variation range, 4.1–10.3 g with CV 29 % versus corresponding figures of range 7.1–7.9 g, CV 4.9 % for the RPAH monofilaments. As predicted by Euler's Buckling Theory, buckling force can be increased by reducing the length of the filament. These results demonstrate that the physical characteristics of the monofilament are important determinants of buckling force and are not necessarily uniform in commercial filaments. The clinical relevance of variance in buckling force remains to be determined.

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Introduction

Diabetes mellitus is associated with a high risk of lower limb amputation and the insensate, neuropathic foot is the most important antecedent.[1–3] Early recognition of 'at-risk' patients followed by intensive footcare can significantly reduce amputation rates.[4–6] While instruments such as the neurometer and biothesiometer exist for measuring sensation, cost and complexity prohibits their use in everyday clinical practice.[7] Instead, the Semmes–Weinstein 5.07/10 g monofilament, an inexpensive and portable tool, has been widely promoted for the purpose of screening patients at risk of ulceration.[8,9] The monofilament has been recommended for this purpose by the International Diabetes Federation and the World Health Organization European St Vincent Declaration.[10] In theory, the Semmes–Weinstein 5.07/10 g monofilament buckles when a force of 10 g is applied. The filament is placed on the patient's foot and if there is significant loss of protective sensation the patient will not be able to detect the presence of the filament at buckling.

As the value of the monofilaments is being recognized, there is an increasing number of sources from where they can be obtained. Since the filaments will be used by many practitioners at different locations, their reliability is essential. Kumar *et al.* have studied the biological response to monofilaments of different buckling force.[11] Our study set out to evaluate how the physical characteristics of monofilaments from different sources can affect their accuracy. For this we chose to study monofilaments obtained from the Hansen's Disease Center (HDC) and those made at our Institute (RPAH).

Methods

HDC monofilaments were purchased from the Hansen's Disease Center, Carville, USA. The filaments used in the RPAH monofilaments were purchased from the Whiting Company, Vermont, USA and were assembled locally.

The buckling force of individual HDC ($n=14$) and RPAH ($n=50$) monofilaments was tested using a Mettler Balance AE260 (Seeby, Anax Scientific Laboratory Supply Company, Sydney, Australia). This has an in-built zeroing device and is calibrated and corrected annually, using

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standard weights. While blinded to the reading on the scale, one observer pressed the monofilament against the balance plate and indicated when the filament buckled. A second observer recorded the weight exerted at that instant.[12] The reproducibility of this method was tested by having 8 observers recording individually (blinded to the other observers' results) the results from the same 10 g monofilament and accuracy shown by a mean result of 9.9 ± 0.7 g, CV 7.7 %.

To assess the effects of varying filament lengths on buckling force, 10 RPAH monofilaments were tested repeatedly as the length of the filament was progressively reduced by cutting four times from an initial length of 4.1 cm to a final length of 3.1 cm. In addition, to assess reliability after extensive use, 5 RPAH filaments were tested before and after 100 usages.

The results of buckling force obtained from the experiments performed at filament lengths of 4.1 and 3.1 cm were used to calculate the constants E and I in the Euler's Buckling Equation (Buckling Force = EI/l^2 where E = Young modulus, $I = \pi d^4/64$ and l = length of the filament).[13]

Statistical analysis was performed using the NCSS (Number Cruncher Statistical System) software. Results are expressed as mean, 95 % confidence intervals (CI) and full range. The interfilament variation between the HDC and the RPAH monofilaments was assessed using coefficient of variation. Reliability of the RPAH monofilaments was assessed by Wilcoxon's signed rank test.

Results

The force generated at buckling by the monofilaments from the two sources, their respective ranges and coefficient of variation are shown in Table 1. Neither type buckled at a force of 10 g. In addition, the HDC monofilament showed a considerable interfilament variation. Visual inspection revealed differences in the length and diameter of the filaments.

As shown in Figure 1, the buckling force increased progressively as the length of the monofilament was reduced. Using the results generated at monofilament lengths of 4.1 and 3.1 cm, the product of the constants EI was calculated to be 110 and 104, respectively. If EI is considered to be 107 (mean of these two determinations), it can be calculated that the correct length of the RPAH monofilament required to exert a buckling force of 10 g is 3.3 cm. Testing 10 RPAH 3.3 cm monofilaments gave a mean force of 10.6 ± 0.6 g, CV 5.3%. The reliability of the monofilament is not jeopardized by repeated use, $z = -0.4$; $p = 0.7$ (Figure 2).

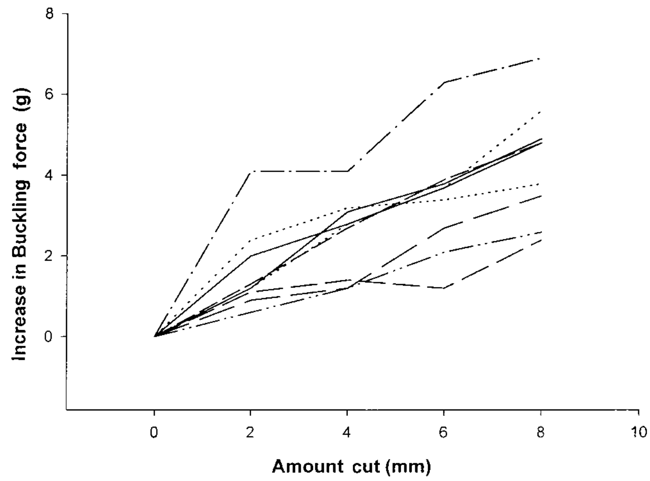

Figure 1. The increase in buckling force with progressive shortening of the filament

Discussion

The Semmes–Weinstein monofilament has the potential of providing a cost-effective way of identifying diabetic

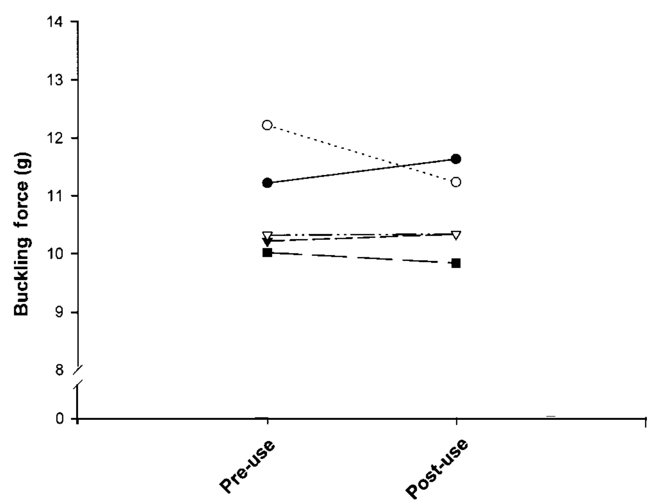

Figure 2. Buckling pressure before and after repeated testing of five RPAH monofilaments on 100 occasions

Table 1. Buckling force of monofilaments from different sources

Semmes–Weinstein monofilament 5.07/10 g	Buckling force (g)[a]	Range (g)	Coefficient of variation (%)
Monofilament from Hansen's Disease Center	6.8 (5.7–7.9)	4.1–10.3	29.1
Monofilament from Royal Prince Alfred Hospital	7.2 (7.1–7.3)	5.6–7.9	4.9

[a] Data are mean and 95 % confidence interval.

patients at risk of neuropathic ulceration.[8–10] This is important, not only for the individual practitioner in the clinical setting, but also from the wider perspective of studying diabetic neuropathic ulceration. For example, if the monofilament is reliable, it allows the easy identification and follow-up of large numbers of patients at a defined stage of sensory loss. In both clinical and research settings, it is important to use monofilaments which reliably buckle at the same force, as different grades of monofilaments may give different clinical information. Variation in buckling force may cause difficulties, particularly in multicentre studies or in comparing data from different centres.[11]

Practitioners tend to purchase a monofilament or obtain one from commercial sources without questioning their accuracy. Institutes where these monofilaments are required in larger numbers may manufacture them (as we have done), again without questioning whether they have the correct physical properties. Our study clearly shows that careful calibration of monofilaments is required prior to their use, if a reliable force is to be applied. In the case of the HDC monofilaments, variations in the type of material as well as the length of the filaments may contribute to the high variation of their buckling force. Although the monofilaments we made 'in house' were of reproducible length and size, they also did not produce a buckling force of 10 g. However, the length to produce the correct buckling force can be easily derived by a simple calibration procedure followed by calculation using the Euler's Buckling Equation which, simply put, states that for any given material it is easier to bend a long pole than a short one.

Our results clearly show that the physical properties of a monofilament can influence their buckling force. Precisely how this variation affects their sensitivity and specificity in categorizing patients of different sensory status is an important but complicated question, as the results may vary according to the degree of sensory loss. At present we are studying this on a large cohort of patients, using monofilaments within a narrow range of buckling force.

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